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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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OFFICE NOTE 149

The U. S. Standard Atmosphere
on the HP67/HP97

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This is an unreviewed manuscript, primarily
intended for informal exchange of information
among NMC staff members.

General

When one of pressure, height, temperature, or potential temperature is input, the program outputs the other three. The program is on a magnetic card, one side containing the program itself, the other side the constants.

Input and output

To operate the program, first read in both sides of the magnetic card. Then key in the input parameter and press the key shown in the table. Outputs will be stored in the registers as shown, including the input parameter.

| Mathematical symbol | Input parameter | Key | Output register |
|---------------------|---------------------------------------|-----|-----------------|
| p | Pressure (mb) | A | A |
| z | Height (m) | B | B |
| T | Temperature ($^{\circ}$ A) | C | C |
| θ | Potential temperature ($^{\circ}$ K) | D | D |

On the HP97 output will also be printed in the order: pressure, height, temperature, potential temperature. On the HP67 output will be flashed on the display in the same order.

Symbols

| | |
|-----------------------|------------------------------------------|
| g | gravity |
| R | gas constant |
| γ | lapse rate of temperature in troposphere |
| $\gamma_a = g/R$ | autoconvective lapse rate |
| $c = \gamma/\gamma_a$ | |
| c_p | specific heat at constant pressure |
| $k^p = R/c_p$ | |

| <u>Parameter</u> | <u>Symbol</u> | <u>Mean sea level</u> | <u>tropopause</u> |
|-----------------------|---------------|-----------------------|-------------------|
| pressure | p | p_o | p^* |
| height | z | $z_o = 0$ | z^* |
| temperature | T | T_o | T^* |
| potential temperature | θ | θ_o | θ^* |

Constants

The basic constants are taken from List, R. J., 1951: Smithsonian Meteorological Tables, 6th rev. ed., Smithsonian Institution, Washington, pp. 265, 266, 289, 308.

| Basic constant | Value |
|----------------|------------|
| γ | .0065 °A/m |
| c | 0.190 284 |
| P_0 | 1013.25 mb |
| T_0 | 288 °A |
| T^* | 218 °A |
| k | 2/7 |
| P | 1000 mb |

The constants stored are

| Register | Symbol | Value |
|----------|-------------------|----------------|
| 0 | p^* (mb) | 234.510 0006 |
| 1 | z^* (m) | 10 769.230 76 |
| 2 | T^* (°A) | 218. |
| 3 | θ^* (°K) | 329.921 3257 |
| 4 | c | 0.190 284 |
| 5 | $-T^*/\gamma$ (m) | -33 538.461 54 |
| 6 | k | 0.285 714 2857 |

Formulas

The constants, p^* , z^* , T^* , θ^* , were calculated from formulas numerically consistent with the programmed calculations for p , z , T , θ :

$$p^* = P_0 \left(\frac{T^*}{T_0} \right)^{1/c}$$

$$z^* = \frac{T^*}{\gamma} \left[\left(\frac{P_0}{p^*} \right)^c - 1 \right]$$

$$\theta_0 = T_0 \left(\frac{P}{P_0} \right)^k$$

$$\theta^* = \theta_0 \exp \left[(c - k) \ln \frac{p^*}{P_0} \right]$$

Outputs, p, z, T, θ , are calculated from the following formulas:

| Output | Troposphere | Stratosphere |
|----------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| p | $p^* \exp \left[\frac{1}{c} \ln \left(\frac{T}{T^*} (z - z^*) + 1 \right) \right]$ | $p^* \exp \left[\frac{1}{c} \frac{-\gamma}{T^*} (z - z^*) \right]$ |
| | $1/c$ | |
| p | $p^* \left(\frac{T}{T^*} \right)^{1/c}$ | $p^* \text{ (see below)}$ |
| p | $p^* \exp \frac{\ln (\theta / \theta^*)}{c - k}$ | $p^* \exp \frac{\ln (\theta / \theta^*)}{-k}$ |
| z | $z^* + \frac{T^*}{-\gamma} \left[\left(\frac{p}{p^*} \right)^c - 1 \right]$ | $z^* + \frac{T^*}{-\gamma} \ln \left(\frac{p}{p^*} \right)^c$ |
| T | $T^* \left(\frac{p}{p^*} \right)^c$ | T^* |
| θ | $\theta^* \exp \left[- (c - k) \ln \frac{p^*}{p} \right]$ | $\theta^* \exp \left(k \ln \frac{p^*}{p} \right)$ |

The U. S. Standard Atmosphere has no temperature below T^* . If input $T \leq T^*$, the program will yield values of p, z, θ at the tropopause. T as input will be output, however.

Note also that z, T, and θ are calculated from p. If z, T, or θ are input, then output p is calculated first from one of the first three formulas, and the other outputs from two of the last three formulas.

Use and status of calculator features.

The parts of the calculator that are used are

Registers 0 - 6, A - D
Labels A - D, 0 - 9
Program memory steps 001 - 112

No flags are used. Display status is FIX DSP 9. Trig status is DEG, but is immaterial to the operation of the program.

Only two returns are held pending for nested subroutines, so you may program the unused parts of the calculator, using this program as a set of

subroutines. However, you must not write a GSB A, GSB B, GSB C, or GSB D within one of your subroutines, otherwise you will violate the limit of three pending returns.

Parts of the calculator available for your program are

- Registers 7 - 9, S0 - S9, E, I
- Labels E, a - e
- Program memory steps 113 - 224
- All flags
- Trig status

Program listing

| | | |
|-----|-------|-------|
| 001 | *LBL1 | 21 11 |
| 002 | STO1 | 35 11 |
| 003 | GBB1 | 23 05 |
| 004 | STO2 | 23 02 |
| 005 | *LBL2 | 21 12 |
| 006 | STO3 | 35 12 |
| 007 | ROL1 | 36 01 |
| 008 | - | -45 |
| 009 | ROL2 | 36 05 |
| 010 | - | -24 |
| 011 | XO1 | 16-45 |
| 012 | STO4 | 22 06 |
| 013 | - | 01 |
| 014 | - | -55 |
| 015 | LN | 32 |
| 016 | *LBL3 | 21 06 |
| 017 | ROL4 | 36 04 |
| 018 | - | -24 |
| 019 | - | 33 |
| 020 | ROL5 | 36 00 |
| 021 | - | -35 |
| 022 | STO5 | 35 11 |
| 023 | *LBL4 | 21 00 |
| 024 | GBB2 | 23 03 |
| 025 | STO6 | 22 01 |
| 026 | *LBL5 | 21 13 |
| 027 | STO7 | 35 13 |
| 028 | ROL6 | 36 02 |
| 029 | XO2 | 16-34 |
| 030 | ENT1 | -21 |
| 031 | - | -24 |
| 032 | ROL4 | 36 04 |
| 033 | - | 52 |
| 034 | - | 31 |
| 035 | ROL5 | 36 00 |
| 036 | - | -55 |
| 037 | STO8 | 35 11 |
| 038 | GBB3 | 23 03 |
| 039 | *LBL6 | 21 01 |
| 040 | ROL7 | 36 00 |
| 041 | ROL8 | 36 11 |
| 042 | - | -24 |
| 043 | GBB4 | 23 04 |
| 044 | - | -35 |
| 045 | GBB | -22 |
| 046 | - | 33 |
| 047 | ROL9 | 36 03 |
| 048 | - | -35 |
| 049 | STO9 | 35 14 |
| 050 | STO2 | 22 02 |
| 051 | *LBL7 | 21 14 |
| 052 | STO5 | 35 14 |
| 053 | ROL3 | 36 03 |
| 054 | - | -24 |
| 055 | GBB4 | 23 04 |
| 056 | - | -24 |

| | | |
|-----|-------|-------|
| 057 | - | 35 |
| 058 | ROL2 | 36 00 |
| 059 | - | -35 |
| 060 | STO8 | 35 11 |
| 061 | GBB5 | 23 05 |
| 062 | GBB3 | 23 03 |
| 063 | *LBL2 | 21 02 |
| 064 | ROL6 | 36 11 |
| 065 | ROL5 | 36 12 |
| 066 | ROL3 | 36 13 |
| 067 | ROL9 | 36 14 |
| 068 | FRST | 16-14 |
| 069 | RTN | 24 |
| 070 | *LBL3 | 21 03 |
| 071 | GBB6 | 23 09 |
| 072 | - | 01 |
| 073 | XO7 | 16-35 |
| 074 | XO7 | -41 |
| 075 | ROL2 | 36 02 |
| 076 | - | -35 |
| 077 | STO6 | 35 13 |
| 078 | RTN | 24 |
| 079 | *LBL5 | 21 05 |
| 080 | GBB5 | 23 09 |
| 081 | - | 01 |
| 082 | - | -45 |
| 083 | XO8 | 16-44 |
| 084 | STO5 | 22 06 |
| 085 | - | 01 |
| 086 | - | -55 |
| 087 | LN | 32 |
| 088 | *LBL6 | 21 06 |
| 089 | ROL5 | 36 05 |
| 090 | - | -35 |
| 091 | ROL1 | 36 01 |
| 092 | - | -55 |
| 093 | STO2 | 35 12 |
| 094 | RTN | 24 |
| 095 | *LBL4 | 21 04 |
| 096 | LN | 32 |
| 097 | - | 00 |
| 098 | XO7 | 16-35 |
| 099 | STO7 | 22 07 |
| 100 | - | -31 |
| 101 | ROL4 | 36 04 |
| 102 | *LBL7 | 21 07 |
| 103 | ROL6 | 36 06 |
| 104 | - | -45 |
| 105 | RTN | 24 |
| 106 | *LBL3 | 21 09 |
| 107 | ROL8 | 36 11 |
| 108 | ROL9 | 36 00 |
| 109 | - | -24 |
| 110 | ROL4 | 36 04 |
| 111 | YX | 31 |
| 112 | RTN | 24 |